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Benefits and Costs of Using Perennial Peanut as Living Mulch for Fruit Trees in Hawai‘i

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Perennial ground covers can be grown under fruit trees as living mulch, a management strategy that is expected to improve soil quality, reduce the need for chemical inputs, and improve the sustainability of tropical fruit orchards (Hensley et al. 1997, Mullahey et al. 1994, Shen and Chu 2004). Its ability to fix atmospheric nitrogen, produce dense cover with little maintenance, and protect soil from erosion has resulted in wide use of perennial peanut throughout Hawai‘i as a living mulch in perennial cropping systems (Figure 1, CTAHR 2009). Although two species of perennial peanut, *Arachis glabrata* and *A. pintoi*, are used as goundcovers worldwide, the stoloniferous *A. pintoi* (Krap. and Greg.) is most commonly used in Hawai‘i.

To help Hawai‘i growers make management decisions about the use of a living mulch, this publication describes experiments conducted to study the effects of perennial peanut planting method and density on (1) groundcover canopy development, (2) selected indicators of soil quality, (3) fruit tree nutrient status, and (4) the cost of establishing the living mulch.

In orchard systems, perennial peanut is commonly established using seeds or cuttings, while rooted plants may be used for smaller-scale plantings. The recommended spacing for cuttings or drilled seed is 1 x 1 ft, although wider spacing of 1 x 3 ft is frequently used because the labor to prepare cuttings and plant the material is costly (Figure 2). Rates recommended for broadcast seed range from 17 to 43 lb/acre (Glover 1994, Hensely et. al. 1997). Unrooted cuttings are often used to avoid paying the seed cost of $15.00/lb. Cuttings require preparation and hand planting, are less able to tolerate adverse conditions during establishment, and may be slower to establish than seedlings (Kerridge and Hardy 1994, Mitschele 2007). Seeding at 40 lb/acre or more is expected to improve the rate of cover establishment in Hawai‘i (Clement and DeFrank 1998, Hensley et al. 1997). However, replicated trials have not confirmed this, nor they have confirmed differences in the rates of establishment between seeded and transplanted peanut.

Fruit tree growers who use *A. pintoi* as a living mulch report improved tree growth and reduced reliance on fertilizers three or more years after establishment (CTAHR 2009). Clement and DeFrank (1998) observed lower growth of peach palm (*Bactris gasipaes*) with a perennial peanut cover than with weed mat during the first 18 months, but the yield differences had ceased to be significant in measurements taken 24 and 30 months after planting. The authors suggested that the initial yield differences were due to N competition, but plant tissue and soil nutrient levels were not reported. Little information is available about the contribution of perennial peanut to soil physical, chemical, and biological quality during the critical period of fruit tree establishment.

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The experimental set-up

Planting and management

Experimental plots were established at the University of Hawai'i Research Stations at Poamoho (Lat. 21°32'58" N Long. 158°05'47" W, elevation 459 ft) and Waimānalo (Lat. 21°20'41" N, Long. 157°44'31" W, elevation 60 ft). Climate and soil characteristics of the two sites are presented in Tables 1–3.

Two trees of three fruit species were planted in plots 120 ft long x 12 ft wide on October 10, 2007 at Waimānalo and October 17, 2007 at Poamoho. Grass strips 6 ft wide were maintained between the plots. The tree species were guava 'Ruby x Supreme' (*Psidium guajava*), sapodilla 'Alano' (*Manilkara zapota*), and mountain apple 'White' (*Syzygium malaccense*). Trees were spaced 15 ft apart within the plots and the planting holes were approximately 1 ft wide by 1.5 ft deep. The fruit trees were fertilized with 2 lb of bone/blood meal incorporated in the planting hole at transplanting and topdressed with 2.5 lb of compost approximately three months after transplanting. Analyses of the bone meal and compost are presented in Table 4.

Figure 1. Two-year-old perennial peanut cover established in an O'ahu orchard.

Four mulch treatments were arranged in a randomized complete block design with three plots per treatment. The mulch treatments were (1) black woven weed mat, (2) perennial peanut seeded at 54 lb/acre, (3) perennial peanut seeded at 18 lb/acre, and (4) stolons planted at low density. The seeding was done on November 9, 2007 at Waimānalo and November 16, 2007 at Poamoho. Seed of cv. CIAT-17434 was purchased from a local vendor and drilled 9 inches apart within rows and 1 or 3 ft between rows at 54 and 18 pounds per acre, respectively. Seed was not inoculated before planting. Black weed mat was applied at the same time as planting occurred. Stolons of *A. pintoi* 'Golden Glory', obtained from a local farm,

Table 1. Average monthly temperature at the experimental sites in 2007 and 2008.

	2007		2008	
Month	Waimanalo	Poamoho	Waimanalo	Poamoho
January	74	71.2	71.8	69
February	72	70.2	72.1	70.1
March	73.5	71.8	74.5	73
April	74.2	71.9	74.3	72.2
May	76.7	75.1	76.7	74.8
June	78.8	77.3	77.9	76.5
July	79	78.2	79.5	77.5
August	79.8	78.9	79.8	77.7
September	79.7	78.2	79.2	77.1
October	--	76.6	78	76.1
November	75.6	73.4	76.2	74.3
December	73.9	72.6	--	72.4

Table 2. Total monthly rainfall at the experimental sites in 2007 and 2008.

	2007		2008	
Month	Waimanalo	Poamoho	Waimanalo	Poamoho
January	3.19	4.85	1.9	1.79
February	2.22	1.88	0.94	5.59
March	4.18	3.08	0.14	0.39
April	2.51	1.48	4.15	2.59
May	0.88	0.59	1.52	0.92
June	0.82	0.49	2.32	0.4
July	2.59	0.33	2.71	1.44
August	0.93	3.28	1.58	0.71
September	1.55	0.48	2.69	0.62
October	--	0.59	3.2	1.65
November	15.12	7.23	4.57	4.49
December	14.54	10.94	--	18

Figure 2. Peanut establishing from stolon cuttings in a weathered soil (Oxisol) on O‘ahu.

were planted in rows 3 ft apart, with 9 inches between stolons within rows, for a density of approximately 14,500 stolons/acre. Cuttings approximately 6 inches long with several nodes and at least one prominent bud or sprout were prepared from older stolons. Most of the leaves were removed from the cuttings and at least three-fourths of the cutting was buried in the ground.

The trees were irrigated with individual emitters at 5 gal/hr for three hours three days a week, and the peanut was irrigated at the same frequency and duration using micro emitters placed on risers 2 ft above ground in between trees within rows. To control weeds, plots were sprayed with glyphosate before planting and were weeded by hand every 6–8 weeks.

Soil quality

Six-inch soil cores were taken at three locations within treatment plots before planting and 7 months after planting. Soil solution was collected 12 months after planting from suction cup lysimeters installed to an 8-inch depth. Chemical analyses were conducted as described in Mitschele (2007).

Soil respiration, volumetric moisture content, and temperature were measured 12 months after peanut establishment. Soil respiration was measured using a CIRAS-1 Gas Analyzer and SRC-1 Soil Respiration Chamber. Aboveground biomass was removed with minimal soil disturbance, and the chamber was placed on the soil surface, measuring the rate of increase for the CO_2 concentration inside the chamber. Moisture content was measured at a 4-inch depth using time domain reflectometry (TDR) on a Field Scout TDR meter. Soil temperature was measured at a 4-inch depth using a digital thermometer.

Table 3. Chemical analysis of soil from the Waimānalo and Poamoho Research Station sites.
Each value is a mean of 12 analyses.

			%	<------------ mg/g ------------>				<------------ mg/dm^3 ------------>			
Location	**Soil Order**	**pH**	**C**	**P**	**K**	**Ca**	**Mg**	**Mn**	**Fe**	**Cu**	**Zn**
Waimanalo	Mollisol	6.5	2.2	306	1098	3695	2315	170	67	8	7
Poamoho	Oxisol	7.0	1.4	522	601	1840	308	159	5	9	9

Table 4. Analysis of bone meal and compost used to fertilize fruit trees.

	----------%----------							----------ug/g----------			
	N	C	P	K	Ca	Mg	Na	Fe	Zn	Cu	B
Bone meal	9.19	46.00	1.71	0.60	3.18	0.13	0.50	481	55	6	1
Compost	1.11	17.63	0.34	0.84	7.48	1.08	0.31	--	782	268	101

Perennial peanut and fruit tree establishment

Perennial peanut establishment at the Poamoho and Waimānalo sites was measured periodically using a 2.70-ft^2 (0.25-m^2) quadrant to determine canopy ground cover at three locations within each plot. Tree height and trunk diameter were measured periodically for the first 7 months of establishment. At 7 months after planting, the third expanded leaf pair of sapodilla and guava from both locations was analyzed for nutrient content. Weed biomass was measured 7 months after planting in the Waimānalo plots. Peanut and weed biomass was also determined 12 months after peanut establishment at the same location.

The experiment's results

Perennial peanut establishment

Peanut canopy establishment was most rapid in the plots seeded at 54 lb/acre, with 75–100 percent coverage within 8 months, followed by the lower seeding rate and the stolon plots, with 25–60 percent coverage in the same period (Figure 3). Canopy development was quicker at Waimānalo than it was at Poamoho, which may reflect Waimānalo's higher temperatures, rainfall, and native soil fertility (Tables 1–3). Twelve months after planting, the peanut treatments were similar in canopy cover at each location, although peanut covered 100 percent of the ground at Waimānalo and only about 70 percent at Poamoho. Greenhouse trials indicated that rhizobial inoculation would have reduced the difference in peanut establishment between the two locations.

Rapid canopy establishment minimizes weeding costs (Hensley et al. 1997). Seven months after planting, the weed biomass was similar between the low seeding rate and stolon treatments, at 0.28 and 0.27 pounds/ft^2, respectively, and lowest at 0.20 pounds/ft^2 in the 54 lb/acre seeding rate. All treatments approached 100 percent cover at the Waimānalo station, with peanut biomass being significantly greater at the highest seeding rate and weed biomass being greatest for the stolon treatment (Figure 4).

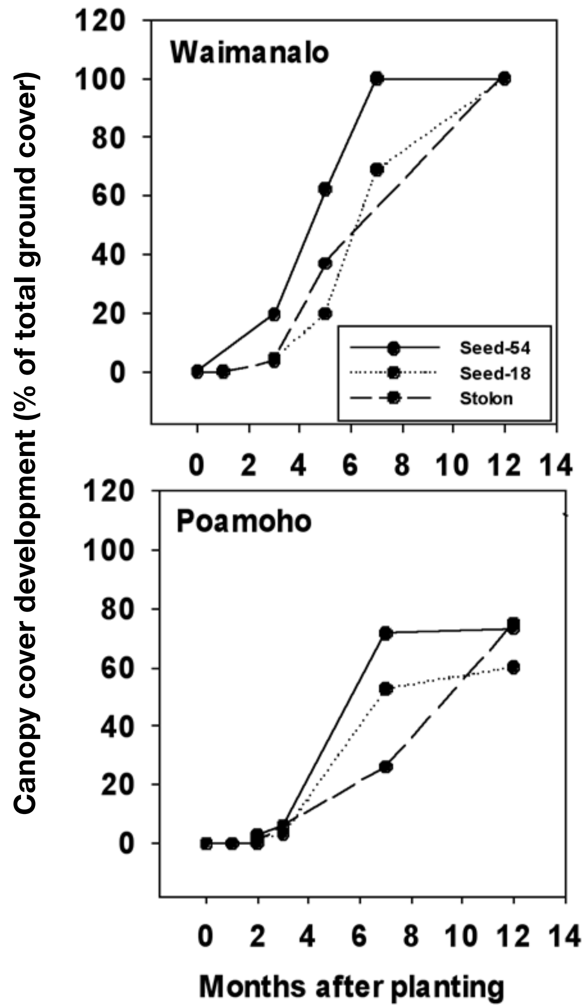

Figure 3. Peanut canopy cover development as a percent of total ground cover. Each value is a mean of six observations.

Soil quality and characteristics

Soil quality is defined by its ability to support ecological processes that promote plant growth (Magdoff and Weil 2005). These processes include water and nutrient retention, nutrient cycling, disease suppression, etc. Physical and chemical characteristics of the station soils before and 7 months after planting are presented in Tables 5 and 6. The effect of peanut mulch on soil chemical characteristics was not different from the weed mat, with the exception of potassium, which was significantly lower in the peanut treatments. Because 7 months may have been too short a time to detect differences in soil quality, additional soil measurements were postponed until 12 months after planting. Significant differences were then observed in soil solution nitrate concentrations and soil CO_2 evolution between the peanut treatments and the black weed mat treatment at both locations (Figures 5 and 6).

Soil respiration is a sensitive measure of its biological activity. Soil respiration values in all peanut treatments

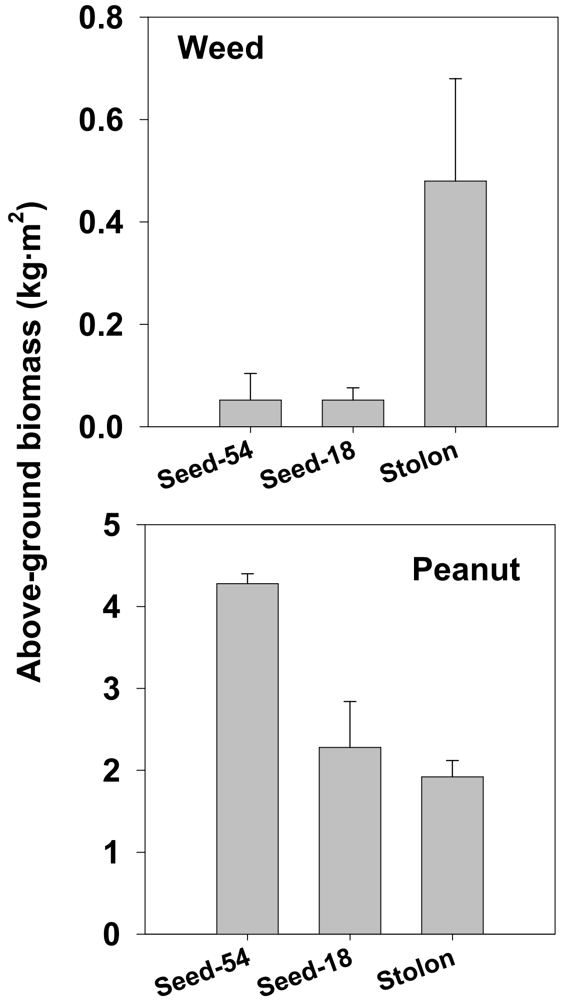

Figure 4. Peanut and weed biomass (fresh weight) at the Waimānalo station 12 months after peanut planting. Each value is a mean of 3 observations.

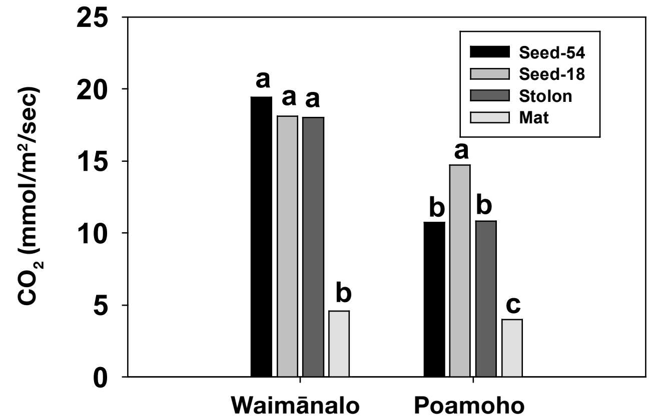

Figure 5. Soil respiration under mulch treatments at Waimānalo and Poamoho 12 months after planting. Bars are means of 9 values. Means within locations with different letters are significantly different at the 5% level.

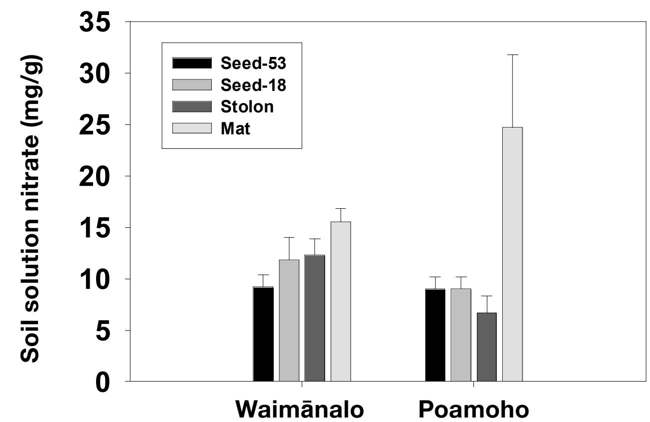

Figure 6. Soil solution nitrate levels under mulch treatments at Waimānalo and Poamoho 12 months after planting. Values are means of 6 values. Error bars are mean standard errors.

were two to four times larger compared to the black weed mat treatments. Respiration values observed under peanut were similar to those reported for forest soils in Hawai'i and elsewhere (Giardina et al. 2004, Jassel et al. 2004). In contrast, nitrate-N levels in soil solution were generally lower under peanut than weed mat treatments (Figure 6), which may reflect competition for N from both the peanut and soil microbial populations. Soil temperatures were also reduced for the peanut treatments compared to weed mat treatments (Figure 7), while moisture levels under peanut were higher than under weed mat (Figure 8). Higher moisture levels may have contributed to increased microbial activity under peanut.

Fruit tree growth

Fruit tree growth was variable, and no significant differences among treatments in trunk diameter or tree height were detected. However, tissue nitrogen content was lower under perennial peanut treatments compared to trees grown with the weed mat, and only trees in the weed mat treatment had tissue nitrogen levels within the critical range established for guava (Figure 9). Other nutrients differed little among treatments (Table 7).

Table 5. Selected soil properties before (pre-plant) and 7 months after (post-plant) perennial peanut establishment at the Poamoho Research Station. An asterisk indicates that the difference between pre-plant and post-plant values is statistically significant. NS indicates no significant difference between the two values.

	Sample			<------	ppm	------	------>	<------	mg/dm^3	------	------>
Treatment	**Time**	**pH**	**% C**	**P**	**K**	**Ca**	**Mg**	**Mn**	**Fe**	**Cu**	**Zn**
Mat	**Pre-plant**	**7.0**	**1.3**	**443**	**574**	**1739**	**315**	**161**	**5**	**9**	**9**
	Post-plant	**7.1**	**1.5**	**512**	**639**	**1998**	**374**	**105**	**3**	**7**	**6**
	Significance	***NS***	***NS***	***NS***	*	***NS***	*	*	*	*	*
Seed-50	**Pre-plant**	**7.2**	**1.5**	**271**	**658**	**1949**	**322**	**156**	**5**	**10**	**9**
	Post-plant	**6.9**	**1.4**	**272**	**435**	**1771**	**292**	**145**	**3**	**7**	**6**
	Significance	***NS***	***NS***	***NS***	*	***NS***	***NS***	***NS***	*	*	*
Seed-20	**Pre-plant**	**7.1**	**1.4**	**365**	**595**	**2000**	**295**	**163**	**5**	**9**	**9**
	Post-plant	**7.0**	**1.4**	**347**	**472**	**1881**	**285**	**128**	**3**	**7**	**6**
	Significance	***NS***	***NS***	***NS***	*	***NS***	***NS***	***NS***	*	*	*
Stolon	**Pre-plant**	**6.8**	**1.4**	**323**	**576**	**1675**	**299**	**156**	**5**	**9**	**8**
	Post-plant	**6.7**	**1.3**	**437**	**415**	**1592**	**286**	**165**	**4**	**8**	**6**
	Significance	***NS***	***NS***	***NS***	*	***NS***	***NS***	***NS***	*	*	*

Table 6. Selected soil properties before (pre-plant) and 7 months after (post-plant) perennial peanut establishment at the Waimānalo Research Station. An asterisk indicates that the difference between pre-plant and post-plant values is statistically significant. NS indicates no significant difference between the two values.

	Sample		%	<------	ppm	------	------>	<------	mg/dm^3	------	------>
Treatment	**Time**	**pH**	**C**	**P**	**K**	**Ca**	**Mg**	**Mn**	**Fe**	**Cu**	**Zn**
Mat	**Pre-plant**	**6.4**	**2.3**	**277**	**938**	**3432**	**2166**	**187**	**65**	**9**	**6**
	Post-plant	**6.5**	**2.2**	**456**	**817**	**41 31**	**2013**	**71**	**52**	**4**	**3**
	Significance	***NS***	***NS***	***NS***	*	*	*	*	*	*	*
Seed-50	**Pre-plant**	**6.5**	**2.1**	**341**	**1111**	**3820**	**2429**	**179**	**68**	**9**	**7**
	Post-plant	**6.6**	**2.0**	**488**	**657**	**4649**	**2127**	**57**	**52**	**4**	**3**
	Significance	***NS***	***NS***	***NS***		*	*	*	*	*	*
Seed-20	**Pre-plant**	**6.5**	**2.3**	**297**	**1173**	**3643**	**2263**	**176**	**66**	**8**	**6**
	Post-plant	**6.6**	**2.1**	**275**	**956**	**4012**	**2195**	**59**	**47**	**4**	**3**
	Significance		***NS***	***NS***	***NS***	*	*	*	*	*	*
Stolon	**Pre-plant**	**6.5**	**2.0**	**307**	**1171**	**3883**	**2404**	**140**	**67**	**7**	**7**
	Post-plant	**6.5**	**1.6**	**335**	**728**	**4033**	**2299**	**63**	**34**	**3**	**3**
	Significance	***NS***	***NS***	***NS***	***NS***	*	*	*	*	*	*

Costs

Installation and maintenance costs on a per-acre basis are summarized in Table 9. Labor is assumed to cost $12.50/hour. The other cost assumptions are detailed below.

Installation

Plastic weed mat cost $1/linear ft, and 2420 linear ft/acre were required, for a total materials cost of $2,400. Seeds cost $15/pound, which means that the higher seeding rate cost $810/acre and the lower one was $270. Stolons cost $6/pound, with 14,500 stolons (116 lb) used for 1 acre for a total cost of $696.

Plastic weed mat installation required 24 hours/acre for a total labor cost of $300. Drilling seed by hand required 15 hours for the high seeding rate and 5 hours for the low rate for costs of $272 and $91, respectively. Walking speed was ~3 min/100 ft. Linear feet walked was 29,185 and 9,728 per acre for high and low seeding rates, respectively. Stolon preparation required 15 hours, and planting required 25 hours, for a total of 40 hours at a cost of $500.

Maintenance

At an irrigation frequency of three times per week for a

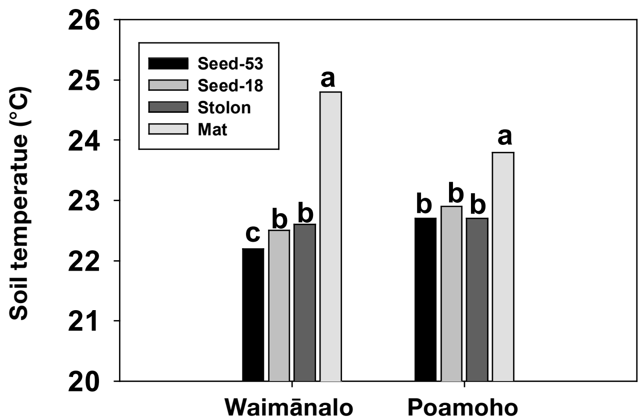

Figure 7. Soil temperatures levels under mulch treatments at Waimānalo and Poamoho 12 months after planting. Values are means of 9 values. Means within locations with different letters are significantly different at the 5% level.

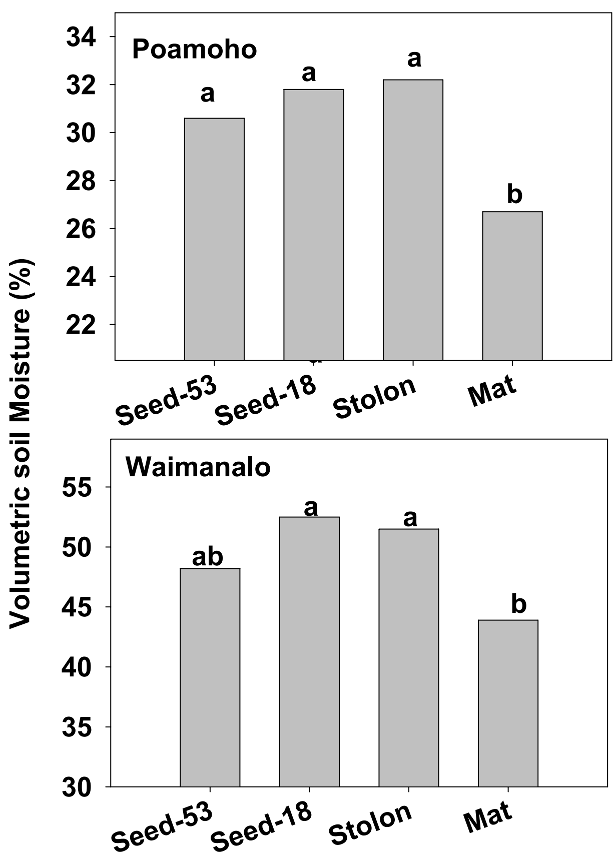

Figure 8. Volumetric soil moisture under mulch treatments at Waimānalo and Poamoho 12 months after planting. Values are means of 9 values. Means within locations with different letters are significantly different at the 5% level.

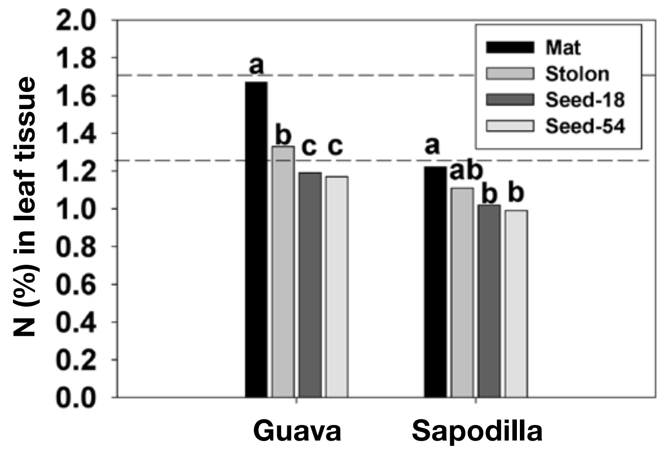

Figure 9. Guava and sapodilla tissue nutrient content under mat and peanut treatments. Values are means of three replications at two locations. Ten leaf pairs (3rd expanded pair from branch tip) were composited from each replication. Dotted lines represent the range of critical N values established for guava (Uchida, 2000). Values with different letters are significantly different at the 5% level.

duration of 3 hours, each tree received 180 gallons/month, or 34,500 gal/acre/month at a planting density of 192 trees/acre, with a water cost of $0.425/1000 gallons. This results in an annual cost of $180. Supplemental irrigation for peanut at the same duration and frequency as the tree requires 228,096 gal/acre/month, or $1,344 per year.

A single spray event required 2 quarts/acre of Ranger Pro® at a cost of $20 and 3 hours of labor at $37.50 for a total cost of $57.50.

Plots were hand-weeded three times during the first 8 months of peanut establishment. This weeding required an estimated 59, 89, and 77 hours/acre for the high seed rate, low seed rate, and stolon treatments and resulted in labor costs of $2212.50, $3337.50, and $2887.50, respectively.

Implications

The perennial peanut mulch treatments were competitive with fruit trees in the short term, particularly for nitrogen. Living mulch cost 55–87 percent more to establish than weed mat, due primarily to the cost of water and the labor for weed control. The most effective way to reduce competition of peanut with trees during establishment may be the limited use of organic or plastic mulch within tree rows or around trees, although this will increase

Table 7. Tissue nutrient levels of guava 8 months after planting. An asterisk indicates statistical significance. NS indicates no statistically significant difference was detected.

		<------ % ------					------>	<------ ppm				------>
	Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**Na**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
Waimanalo	**Mat**	**1.72**	**0.25**	**1.94**	**0.82**	**0.38**	**0.07**	**54**	**48**	**9**	**10**	**29**
	Seed-54	**1.25**	**0.32**	**2.04**	**0.97**	**0.36**	**0.09**	**44**	**36**	**15**	**9**	**32**
	Seed-18	**1.12**	**0.28**	**2.08**	**0.91**	**0.34**	**0.09**	**48**	**39**	**20**	**9**	**32**
	Stolon	**1.3**	**0.27**	**2.27**	**0.83**	**0.32**	**0.73**	**46**	**35**	**8**	**9**	**29**
Poamoho	**Mat**	**1.6**	**0.19**	**2.09**	**0.93**	**0.23**	**0.01**	**53**	**210**	**14**	**8**	**27**
	Seed-54	**1.09**	**0.22**	**1.90**	**1.00**	**0.23**	**0.03**	**47**	**136**	**17**	**8**	**32**
	Seed-18	**1.24**	**0.19**	**1.84**	**0.98**	**0.23**	**0.03**	**54**	**171**	**15**	**8**	**28**
	Stolon	**1.34**	**0.20**	**1.80**	**1.01**	**0.24**	**0.02**	**51**	**184**	**15**	**9**	**30**
ANOVA												
Treatment (T)		***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	*	***	***NS***
Locatio n (L)		***NS***	***	***NS***	**	***	***	***NS***	***	***NS***	***	***NS***
T x L		***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

Table 8. Tissue nutrient levels of sapodilla 8 months after planting. An asterisk indicates statistical significance. NS indicates no statistically significant difference was detected.

		<------ % ------					------>	<------ ppm				------>
	Treatment	**N**	**P**	**K**	**Ca**	**Mg**	**Na**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
Waimanalo	**Mat**	**1.17**	**0.11**	**1.09**	**1.38**	**0.32**	**0.9**	**52**	**65**	**7**	**5**	**25**
	Seed-54	**1.09**	**0.16**	**1.11**	**1.5**	**0.4**	**0.09**	**49**	**42**	**7**	**5**	**36**
	Seed-18	**1.05**	**0.11**	**1.05**	**1.55**	**0.4**	**0.09**	**89.00**	**44**	**8**	**5**	**36**
	Stolon	**1.16**	**0.13**	**1.19**	**1.24**	**0.35**	**0.1**	**50**	**59**	**10**	**6**	**27**
Poamoho	**Mat**	**1.26**	**0.11**	**1.23**	**1.20**	**0.4**	**0.15**	**83**	**47**	**8**	**5**	**28**
	Seed-54	**0.90**	**0.13**	**1.03**	**1.09**	**0.41**	**0.21**	**53**	**24**	**6**	**5**	**25**
	Seed-18	**0.98**	**0.10**	**0.93**	**1.56**	**0.56**	**0.16**	**66**	**27**	**7**	**4**	**32**
	Stolon	**1.04**	**0.15**	**1.03**	**1.34**	**0.45**	**0.15**	**85**	**35**	**9**	**5**	**35**
ANOVA												
Treatment (T)		***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	*	***NS***	***NS***
Location (L)		***NS***	***NS***	***NS***	***NS***	*	***	***NS***	*	***NS***	***NS***	***NS***
T x L		***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***	***NS***

Table 9. Estimated cost per acre of mulch establishment (12 months) in the Waimānalo and Poamoho Research Station trials.

	Weed mat	Seeded at 54 lb/acre	Seeded at 18 lb/acre	Cuttings (stolons)
Installation				
Materials	$2,400	$810	$270	$696
Labor	$300	$272	$91	$500
Irrigation	$180	$1,344		
Weed control				
Chemicals		--------------------------$58--------------------------		
Labor		$2,213	$3,337	$2,888
Total	$2,880	$4,697	$5,100	$5,486

costs associated with peanut establishment. For example, Typar® weed barrier circles would cost $3.50 per tree for 292 trees per acre and increase costs by $1,022 per acre. However, the higher respiration rate under living mulch demonstrated the potential of peanut to enhance soil microbial activity compared to weed mat alone.

The 54-lb/acre seeding rate was the most cost-effective option of the three mulch treatments. The stolons cost nearly as much as the seed for the 54-lb/acre treatment, while the labor costs were almost double. When the high installation costs are added to the extra cost of weed control for establishment from cuttings, it cost 7.5 percent more than the 54-lb/acre treatment. The higher installation cost of the 54-lb/acre rate compared with the 18-lb/per acre rate were offset by the higher labor cost associated with weeding in the lower seeding rate. Inoculation with rhizobia, not used in this trial, would cost very little and might improve establishment, particularly in poor soils.

The cost of establishing seeded perennial peanut living mulch may be reduced by (1) planting at the beginning of the wet season to reduce or eliminate the need for supplemental irrigation, (2) replacing hand weeding with chemical control, and (3) utilizing mechanization (i.e., tractor and appropriate implements) for drilling or broadcasting and incorporating. For growers interested in organic certification, establishment of living mulch using herbicides must be done three or more years before applying. If herbicide use is not an option, then the peanut should be planted as densely as possible, the seeds should be inoculated before planting, and regular mowing should be done as soon as the canopy closes.

The use of living mulch has the potential to improve the sustainability of tropical fruit agro-ecosystems in the long run, although cost issues and short-run competition can reduce the expected benefits. The relative cost of the weed mat treatment may increase more than the peanut treatments in the long run as shipping costs increase. While some of the benefits associated with increased sustainability may not result in an increased return to producers, consumers may be expected to pay more for items produced if they are labeled as using sustainable methods, and this increased return should also be examined before a grower makes a final decision.

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